Current Practice on the Use of Admixtures to Enable Successful Manufacture of Concrete with Low Portland Cement Content

By

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Outline

- Commercial Mix Designs with HVFA
- The setting time and early strength challenge
- Chemical admixture options and approach
- Making HVFA concrete with minimal set and strength delay
- Keeping an eye on the potential for unexpected cement-SCM-admixture performance

General Mix Design Strategy for HVFA Concrete Mixtures

- Minimum Powder Content 375-700 pcy (220-420 kg/m³)
- Cement/SCM 40-60%
- w/c <0.40
- WR/MRWR/HRWR Essential
- Set Accelerator Req’d for set/early strength
- Air Entrainment Freeze-thaw applications

Benefits of SCMs

- Lower cost
- Use of by-products
- Decreased permeability
- Reduced sulfate attack
- Reduced efflorescence
- Reduced shrinkage
- Reduced heat of hydration
- Reduced alkali silica reactivity
- Increased workability and slump retention
- Improved finishing
- Reduced bleeding
- Reduced segregation

Then, why aren’t SCMs used consistently at 40-50% cement replacement??
Factors inhibiting increased cement replacement by SCMs

- Retarded set and strength development *
- Excessive retardation at cold temperatures *
- Inconsistent air entrainment *
- Prescription specified mix designs
- Spot shortages of quality materials

*Opportunity for Chemical Admixtures

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SEM of FA and Cement Hydration

Fly Ash Replacement Level and Setting Time

BSA = 819 m²/kg, main particle size ~ 6 micron

Seasonal Adjustment of Fly Ash Content

<table>
<thead>
<tr>
<th></th>
<th>Hot Weather</th>
<th>Moderate Weather</th>
<th>Cold Weather</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>300 lbs.</td>
<td>325 lbs.</td>
<td>400 lbs.</td>
</tr>
<tr>
<td>Fly ash</td>
<td>150 lbs.</td>
<td>125 lbs.</td>
<td>100 lbs.</td>
</tr>
</tbody>
</table>

% Replacement 33% 28% 20%

Lower SCMs at lower temp

http://www.ci.austin.tx.us/greenbuilder/fs_flyashconcrete.htm

Water Reduction by SCMs - Replacement Level & Size

Ash collected from precipitator and air classified into 3 fractions.

Increased Fineness = more spherical morphology
More lubricating effect and packing density

http://www.ci.austin.tx.us/greenbuilder/fs_flyashconcrete.htm
Effect of 40% FA on Concrete Performance

<table>
<thead>
<tr>
<th>Mix</th>
<th>Fly Ash (Class F)</th>
<th>Water</th>
<th>Admixture</th>
<th>Slump</th>
<th>Air</th>
<th>Initial</th>
<th>Final</th>
<th>Comp. Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>0.50</td>
<td>1.5</td>
<td>4.22</td>
<td>6.33</td>
<td>4:22</td>
<td>6:33</td>
<td>7.0 (1000 psi)</td>
</tr>
<tr>
<td></td>
<td>+ fly ash</td>
<td>0.50</td>
<td>0.9</td>
<td>9:20</td>
<td>13:01</td>
<td>3.1</td>
<td>11:37</td>
<td>3.1 (4000 psi)</td>
</tr>
</tbody>
</table>

slump much higher than baseline
5 hr reduction in set
1D strength = 44% of baseline
7D strength = 60% of baseline

Effect of HVFA on Concrete Performance – water cut

<table>
<thead>
<tr>
<th>Mix</th>
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<th>Air</th>
<th>Initial</th>
<th>Final</th>
<th>Comp. Strength</th>
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<td>1.5</td>
<td>4.22</td>
<td>6.33</td>
<td>4:22</td>
<td>6:33</td>
<td>7.0 (1000 psi)</td>
</tr>
<tr>
<td></td>
<td>+ fly ash</td>
<td>0.47</td>
<td>0.9</td>
<td>8:27</td>
<td>11:59</td>
<td>3.4</td>
<td>13.8</td>
<td>4.4 (4000 psi)</td>
</tr>
</tbody>
</table>

6% water reduction with fly ash
similar slump as baseline
4 hr retardation in set
1D strength = 48% of baseline
7D strength = 70% of baseline

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Strategies to choosing Chemical Admixture

- Choose appropriate dispersing chemistries
  - maximum dose/slump efficiency because the lower the dosage of water reducing admixtures to achieve a particular degree of concrete workability (slump), the less the impact on the rate of cement hydration.
  - maximize water reduction/increment of set time increase
  - maximize early strength development
- Choose appropriate accelerating additives
  - desires ones that give synergies with dispersing chemistries

Comparison of dose/slump efficiency by reducer types

- PCE most dose/slump efficient

Comparison of water reduction/set time efficiency by reducer types

- PCE gives best slump/Δ set
Maximize early strength development by PC design

PC can be designed for:
- high early strength
- quick slump gain
- long slump life without extended set

Effect of Four PC on Set Time of Concrete with 40% Slag

Mix design:
- 708 lb/yd³
- 40% Slag
- w/cm = 0.45

Set time differences among PCs increase with both dosage and lower temperatures

Effect of Slag Content and PC Type on Setting Time

Set time longer and set time differences higher in mixes with higher slag content

Effect of Cement-Fly Ash-Admixture Combinations on Concrete Performance

Additional 18% water reduction with polycarboxylate-based HRWR

Effect of Cement-Fly Ash-Admixture Combinations on Concrete Performance

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NSFC/Calcium Nitrite vs. PC/Calcium Nitrite

Synergistic Strength Increase:
PC/Ca Nitrite vs. NSFC/Ca Nitrite

Why?
- Hydration kinetics?
- Microstructure development?
- ITZ?
- Pore size distribution?
- Other?

Effect of Chemical Admixtures on the Microstructural Development of Portland Cement Mortars and Concretes

<table>
<thead>
<tr>
<th>Materials</th>
<th>Concrete</th>
<th>Mortar</th>
<th>Cement paste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>420 kg/m³</td>
<td>420 kg/m³</td>
<td>200 g</td>
</tr>
<tr>
<td>Natural Sand, FM 6.61</td>
<td>830 kg/m³</td>
<td>801 kg/m³</td>
<td>-</td>
</tr>
<tr>
<td>Stone, ASTM C33, No.67</td>
<td>1040 kg/m³</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Water</td>
<td>180 kg/m³</td>
<td>180 kg/m³</td>
<td>56 g</td>
</tr>
<tr>
<td>w/c</td>
<td>0.43</td>
<td>0.43</td>
<td>0.28</td>
</tr>
<tr>
<td>PCS dosage (% s/c)</td>
<td>0.13%</td>
<td>0.13%</td>
<td>0.13%</td>
</tr>
<tr>
<td>NSFC dosage (% s/c)</td>
<td>0.6%</td>
<td>1.2%</td>
<td>1.2%</td>
</tr>
<tr>
<td>CANI dosage (% s/c)</td>
<td>1.0%</td>
<td>1.0%</td>
<td>1.0%</td>
</tr>
</tbody>
</table>

C. Porteneuve, A. Jeknavorian, F. Serafin, K.L Scrivener, E. Gallucci, G. Gal
American Ceramic Society Meeting, Baltimore, April 2005

PC/CANI vs NSFC/CANI – Concrete Performance

<table>
<thead>
<tr>
<th></th>
<th>PCS + CANI</th>
<th>NSFC + CANI</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-minute Slump (mm)</td>
<td>229</td>
<td>216</td>
</tr>
<tr>
<td>Air (%)</td>
<td>2.5%</td>
<td>2.9%</td>
</tr>
<tr>
<td>Initial setting time (Minutes)</td>
<td>3.47</td>
<td>4.15</td>
</tr>
</tbody>
</table>

PC/Cani gave shorter set and higher strength than NSFC/CANI

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American Ceramic Society Meeting, Baltimore, April 2005

PC/CANI vs NSFC/CANI – Mortar & Paste Performance

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PC/CANI vs NSFC/CANI – Calorimetry

PC/CANI accelerates
NSFC/CANI retards

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Probing Concrete Microstructure with Backscattered Scanning Electron Microscopy (BSEM)

PC +a Calcium Nitrite  
NSFC + Calcium Nitrite

Gap size, μm  
PC + Ca(NO₂)₂  
NSFC+ Ca(NO₂)₂

C-S-H layer thickness  
1.5  
0.8

Effect of PCE/Calcium Nitrite for 60/40 OPC/Ash Concrete

<table>
<thead>
<tr>
<th>Mix</th>
<th>Fly Ash</th>
<th>Water</th>
<th>Admixture</th>
<th>Slump</th>
<th>Initial Set</th>
<th>Final Set</th>
<th>Comp. Strength</th>
<th>1-Day</th>
<th>7-Day</th>
<th>28-Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0</td>
<td>0.50</td>
<td></td>
<td>140</td>
<td>1.5</td>
<td>4.22</td>
<td>6.33</td>
<td>19.6</td>
<td>27.5</td>
<td></td>
</tr>
<tr>
<td>+ fly ash</td>
<td>40</td>
<td>0.50</td>
<td></td>
<td>215</td>
<td>0.9</td>
<td>9.20</td>
<td>13.01</td>
<td>3.1</td>
<td>11.7</td>
<td>16.9</td>
</tr>
<tr>
<td>+6% water cut</td>
<td>40</td>
<td>0.46</td>
<td></td>
<td>145</td>
<td>0.9</td>
<td>8.27</td>
<td>11.99</td>
<td>3.4</td>
<td>13.8</td>
<td>19.4</td>
</tr>
<tr>
<td>+18% water cut</td>
<td>40</td>
<td>0.38</td>
<td>0.13% PC-500</td>
<td>145</td>
<td>3.2</td>
<td>7.48</td>
<td>10.59</td>
<td>5.5</td>
<td>22.1</td>
<td>28.2</td>
</tr>
<tr>
<td>+CANI</td>
<td>40</td>
<td>0.38</td>
<td>2.5% Ca Nitrite</td>
<td>165</td>
<td>3.6</td>
<td>5.20</td>
<td>8.15</td>
<td>6.0</td>
<td>24.3</td>
<td>30.1</td>
</tr>
</tbody>
</table>

24% water reduction with fly ash  
slight increase in slump from baseline  
1 hr retardation from baseline  
1D strength = 86% of baseline  
7D strength > baseline

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PC/CANI vs NSFC/CANI – CH by SEM

<table>
<thead>
<tr>
<th>Image</th>
<th>PCS+CANI</th>
<th>NSFC+CANI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.6</td>
<td>10.8</td>
</tr>
<tr>
<td>2</td>
<td>15.4</td>
<td>8.6</td>
</tr>
<tr>
<td>3</td>
<td>13.5</td>
<td>8.7</td>
</tr>
<tr>
<td>4</td>
<td>11.4</td>
<td>6.4</td>
</tr>
<tr>
<td>5</td>
<td>10.8</td>
<td>8.4</td>
</tr>
<tr>
<td>6</td>
<td>15.2</td>
<td>-</td>
</tr>
</tbody>
</table>

Average CH amount (%) 12.7 8.6

Standard deviation (%) 2.4 1.6

More CH for PC/CANI than NSFC/CANI

Performance Map of HRWR/HES System

<table>
<thead>
<tr>
<th>Comp. Strength</th>
<th>Low 10 mins</th>
<th>High 63% 30 mins</th>
<th>Medium 62% 100 mins</th>
<th>High 62% 100 mins</th>
<th>High 65% 20 mins</th>
<th>High 66% 20 mins</th>
<th>High 68% 20 mins</th>
<th>High 69% 20 mins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Set</td>
<td>Low 10 mins</td>
<td>High 71% 10 mins</td>
<td>Medium 73% 110 mins</td>
<td>High 73% 110 mins</td>
<td>High 71% 45 mins</td>
<td>High 81% 45 mins</td>
<td>High 80% 45 mins</td>
<td>High 81% 45 mins</td>
</tr>
<tr>
<td>Final Set</td>
<td>Low 10 mins</td>
<td>High 77% 45 mins</td>
<td>Medium 78% 105 mins</td>
<td>High 78% 105 mins</td>
<td>High 71% 60 mins</td>
<td>High 91% 60 mins</td>
<td>High 88% 60 mins</td>
<td>High 91% 60 mins</td>
</tr>
</tbody>
</table>

Strength target met w/ low alkali cement + high CaO ashes

Set performance difficult to predict, fly ash-dependent

Tools for Probing Paste Performance (New Standards)

ASTM Subcommittee C01.48/C09.48
Performance of Cementitious Materials-Admixture Combinations

ASTM C 1679-07
Standard Practice for Measuring Hydration Kinetics of Hydraulic Cementitious Mixtures Using Isothermal Calorimetry
Proper selection of admixture systems (HRWRs and accelerators) can enable use of high volume cement replacement by SCMs.

HRWRs, through the use of polycarboxylate technology, can be optimized for use with HVFA concrete mixes.

One cannot assume admixture systems will automatically work as usual when using high levels of SCMs.

Most SCMs have some impact on the sulfate balance.

Portland cement is usually optimized for mixes without SCM.

Isothermal or semi-adiabatic calorimetry can detect potential interactions.